AN ANISOTROPIC ILLUMINATION MODEL OF SEYFERT I GALAXIES

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ABSTRACT

We present a new model of accretion disk where the disk luminosity is entirely due to the reprocessing of hard radiation impinging on the disk. The hard radiation itself is emitted by a hot point source above the disk, that could be physically realized by a strong shock terminating an aborted jet. This hot source contains ultra-relativistic leptons scattering the disk soft photons by Inverse Compton (IC) process. Using simple formula to describe the IC process in an anisotropic photon field, we derive a self-consistent solution in the Newtonian geometry, where the angular distribution of soft and hard radiation, and the radial profile of the disk effective temperature are determined in a univocal way. This offers an alternative picture to the standard accretion disk emission law, reproducing individual spectra and predicting new scaling laws that fit better the observed statistical properties. General relativistic calculations are also carried out. It appears that differences with the Newtonian case are weak, unless the hot source is very close to the black hole.

Keywords: black hole; galaxies: nuclei; galaxies: Seyfert; relativity

1. INTRODUCTION

It is widely believed that the high energy emission of AGNs is produced by Comptonization of soft photons by high energy electrons or pairs. Besides, for Seyfert galaxies, some observational facts support the idea that high energy radiation can be primarily produced and reflected on a cold surface, producing a fair fraction of thermal UV-optical radiation (Clavel et al. (1992),Pounds et al. (1990)). We then propose a new model involving a point source of relativistic leptons located above the disk (that could be physically realized by a strong shock terminating an aborted jet) emitting hard radiation by Inverse Compton (IC) process on soft photons produced by the accretion disk. The disk itself radiates only through the re-processing of the hard radiation impinging on it, i.e. we do not suppose any internal energy dissipation (this is a relatively good approximation since the disk supplies its jet with almost all the available gravitational power, being then weakly dissipative (Ferreira & Pelletier (1995))) . Such a geometry is highly anisotropic, which takes a real importance in the computation of IC process (Ghisellini et al. (1991), Henri & Petrucci (submitted)). We treat both Newtonian and general relativistic cases, deriving a self-consistent solution in the Newtonian case. We present here the main equations describing the radiative balance between the hot source and the disk, as well as the most important results supplied by the model.

2. The model

Let us consider a relativistic charged particle, characterized by its the Lorentz factor $\gamma = (1-\beta^2)^{-1/2}$, and the soft photon field, characterized by the intensity distribution $I_\nu(\vec{k})$. We assume that the Thomson approximation is valid; in this limit, the rate of energy emitted by the particle by inverse Compton process is:

$$dP \propto \gamma^2 \int I_\nu(\vec{k})(1-\beta\vec{k_0}.\vec{k})^2 d\Omega d\nu \qquad (1)$$

$\vec{k}$ and $\vec{k}_0$ are respectively the unit vectors along the photon and the particle velocity. Thus, one deduced with the hypothesis of an isotropic distribution of high energy particles, the plasma emissivity of the hot source (Henri & Petrucci (submitted)):

$$\frac{dP}{d\Omega} \propto [(3J-K) - 4H\mu + (3K-J)\mu^2] \qquad (2)$$

where the 3 Eddington parameters, J, H and K are defined by:

$$\begin{aligned} J &= \frac{1}{2}\int I_\nu(\vec{k}) d\mu d\nu & (3)\\ H &= \frac{1}{2}\int I_\nu(\vec{k})\mu d\mu d\nu & (4)\\ K &= \frac{1}{2}\int I_\nu(\vec{k})\mu^2 d\mu d\nu & (5)\end{aligned}$$

and $\mu = \cos\theta$ is the cosine of the impinging angle of radiation (cf Fig. 2.). Under the hypothesis that the disk reprocesses the whole radiation impinging on it, we equalize the power absorbed and emitted by a surface element dS of the disk at a distance r of

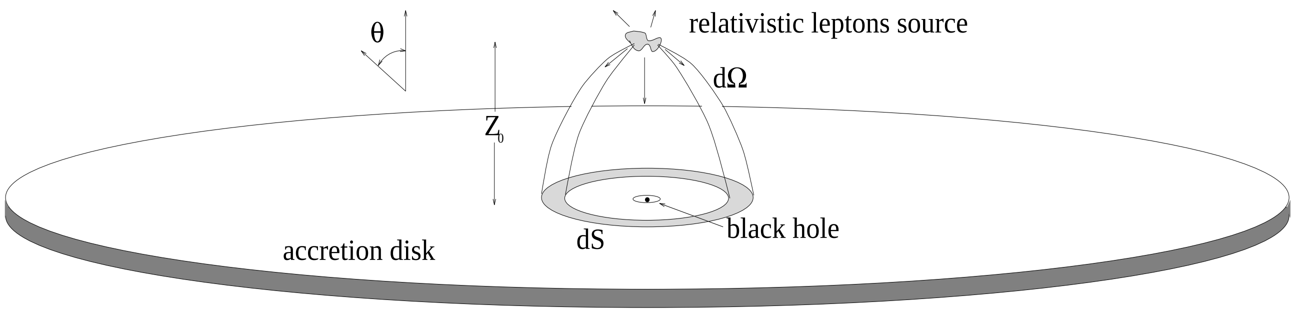

Figure 1: The general picture of the model. We have also drawn the trajectory of a beam of photons emitted by the hot source in a solid angle $d\Omega$ and absorbed by a surface ring dS on the disk.

the black hole (cf Fig. 2.):

$$F(r)dS = \frac{dP}{d\Omega}d\Omega = -\mu^3\frac{dP}{d\Omega}\frac{dS}{Z_0^2} \quad (6)$$

$$= \pi I(r)dS \quad (7)$$

where Z_0 is the height of the hot source above the disk (cf Fig. 2.). In equation (7), one supposes that the disk radiates like a black body. Finally, combining Equations (2), (6) and (7), one obtain a linear system of equations between J, H and K. By setting its determinant to zero, we finally find universal solutions for the hot source and disk emissivity laws. The relativistic case of a Kerr metrics has also been solved (Petrucci & Henri submitted). In this case, the overall spectra depend on a, the angular momentum by unit mass of the black hole, and on the ratio Z_0/M of the height of the hot source on the black hole mass. The whole computations in the Newtonian and Kerr geometry can be found in (Henri & Petrucci (submitted)) and (Petrucci & Henri (submitted)).

3. Results

3.1. Angular distribution of the hot source

It appears from Eq. (2) that the anisotropy of the soft photon field about level with the hot source, leads to an anisotropic Inverse Compton process, with much more radiation being scattered backward than forward. Such a anisotropic re-illumination could naturally explain the apparent X-ray luminosity, usually much lower than the optical-UV continuum emitted in the blue bump. It can also explain the equivalent width observed for the iron line, which requires more impinging radiation than what is actually observed. We plot in Figure 2 the angular distribution of the power emitted by the hot source in Newtonian metrics and for different values of the source height in Kerr metrics. It appears that the closer the source to the black hole is, the less anisotropic the photon field is. This is principally due to the curvature of geodesics making the photons emitted near the black hole arrive at larger angle than in the Newtonian case.

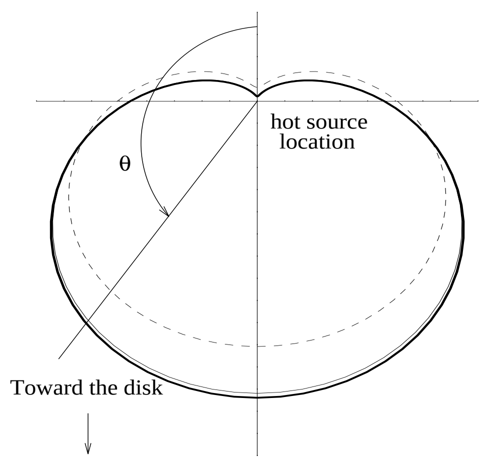

Figure 2: Polar plots of $\frac{dP}{d\Omega}$ for $Z_0/M = 100$ (solid line) and $Z_0/M = 10$ (dashed line) in Kerr metrics with $a = 0.998$. The bold line corresponds to the Newtonian metrics

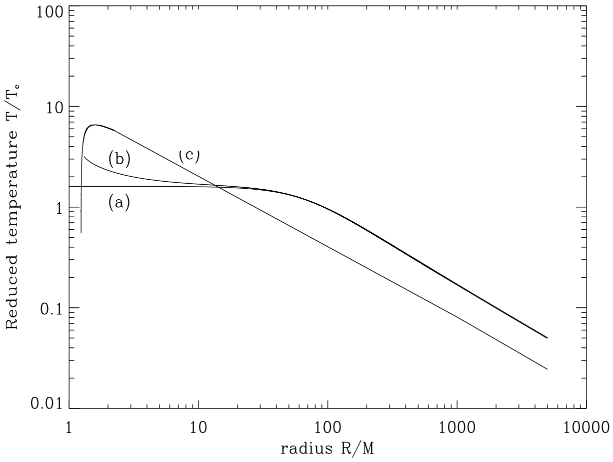

Figure 3: *Effective temperature versus r for $Z_0/M = 70$.*
a) Our model in Newtonian metrics
b) Our model in Kerr metrics
c) Standard accretion disk

3.2. Disk temperature profile

The radiative balance between the hot source and the disk allows to compute the temperature profile on the disk surface. It is, in fact, markedly different from "standard accretion disk model" as shown in Figure 3. Indeed, even if at large distances, all models give the same asymptotic behavior $T \propto R^{-3/4}$, in the inner part of the disk, it keeps increasing in "standard model" whereas, in our model, for $R \leq Z_0$, the temperature saturates around a characteristic value T_c. Indeed, the power radiated by the disk is essentially controlled by the angular distribution of the hot source $\dfrac{dP}{d\Omega}$ (cf Eq. 6) which is approximatively constant for $R \leq Z_0$ (i.e. $\theta \simeq \pi/4$). The differences between Newtonian and Kerr metrics comes only from Gravitational and Doppler shifts, which are only appreciable for $R \leq 5M$. Thus, unless Z_0 is itself small enough, these shifts concern only a small fraction of the emitting area at $T = T_c$, and modified hardly the UV to X-ray spectrum.

3.3. The overall spectra

The overall UV to X-ray spectra can be deduced from this model. The bulk of the energy coming from the disk is emitted on the blue and the ultraviolet, giving the well-known "blue-bump" observed in most quasars and many AGNs. On the other hand, the high energy spectrum is a power law with a exponentially cut-off. It depends directly on the relativistic particle distribution adopted.

3.3.1. Influence of the inclination angle

One can see on Figure 4 Newtonian and Kerr maximal spectra for different inclination angles for $Z_0/M = 10$. For all inclination angles, the Kerr spectra are always weaker in UV and brighter in X-ray than the Newtonian ones. However, the difference

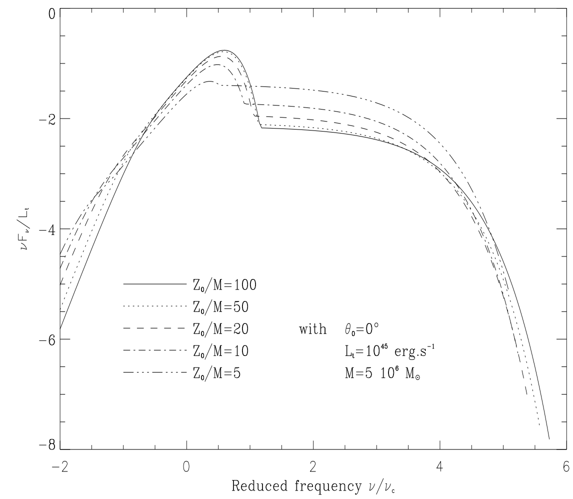

Figure 5: *Differential power spectrum for different values of Z_0 for the Kerr maximal case. We use reduced coordinates.*

tends to be less visible for the highest inclination angles. This can be explained easily by the fact that, for high inclination angle, the part of the disk moving toward the observer emits blue-shifted radiation, compensated by the red-shifted radiation from the other parts. These effects are much less pronounced for high Z_0/M values because the emission area is much larger, and thus is less affected by relativistic corrections.

3.3.2. Influence of the hot source height

Figure 5 shows the overall spectrum, for different values of Z_0/M. The relativistic effects become important for values of Z_0/M smaller than about 50. They produce a variation of intensity lowering the blue-bump and increasing the hard X-ray emission. The change in the UV range is due to the transverse Doppler effect between the rotating disk and the observer, producing a net red-shift. In the X-ray range, the variation is due to the high energy dependence on Z_0/M (cf Figure 2). The observed X/UV ratio can then be strongly altered by these effects. Quantitatively, the luminosity ratio between the maximum of the blue-bump and the X-ray plateau goes from $\simeq 30$ in the Newtonian case, to $\simeq 1.5$ for $Z_0/M = 5$.

3.4. Scaling laws

With some further assumptions, the model predicts scaling laws quite different from the standard accretion models. If one assumes a constant high energy cut-off (possibly fixed by the pair production threshold) and a constant solid angle subtended by the hot source, then the following mass scaling laws apply:

$$\begin{aligned} T_c &= \textit{constant} \\ L_c &\propto M^2 \end{aligned}$$

That is, the disks have all the same central temperature, independent of the mass, and a luminosity vary-

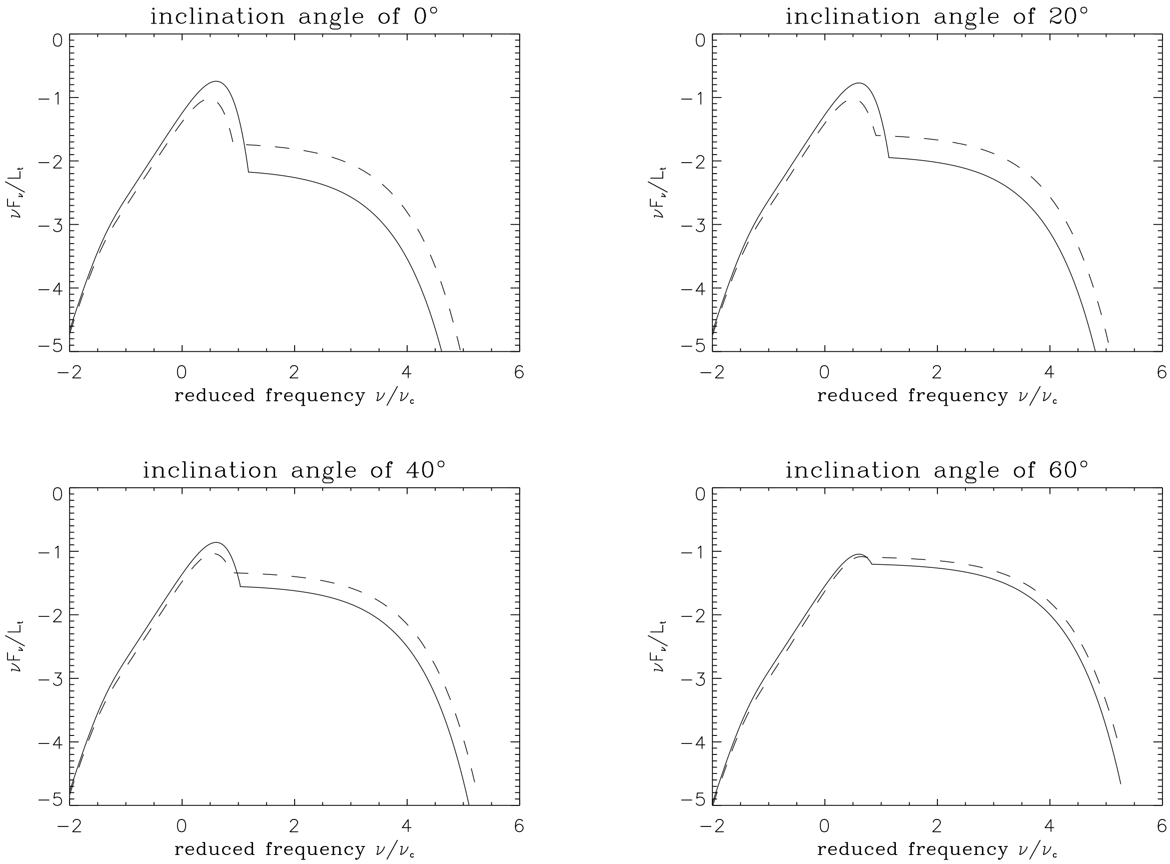

Figure 4: *Differential power spectrum for different inclination angle, in the Newtonian (solid lines) and the Kerr maximal (dashed lines) cases for $Z_0/M = 10$. We use reduced coordinates.*

ing like the mass squared.

4. CONCLUSIONS

We have developed a new model for Seyfert galaxies emission, which offers an alternative picture to the standard accretion disk emission law. It reproduces individual spectra in agreement with observations, and predicts new scaling laws that fit better the observed statistical properties. A more complete work has to be done to explain the exact mechanism of emission of the hot source, supposed to be realized by a strong shock terminating an aborted jet.

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